BELLCOMM, INC.
1100 Seventeenth Street, N.W. Washington, D.C. 20036

SUBJECT: A Rationale and Guidelines for the Development of a Lunar Flying Unit for Lunar Exploration - Case 730

DATE: Dec. 22, 1967

FROM: R. Sehgal

ABSTRACT

A rationale and guidelines for the development of a Lunar Flying Unit (LFU) for lunar exploration are presented. Based on the criteria outlined, the LFU can be developed and man-rated over a two year period for an approximate overall cost of 10 million dollars. It is recommended that this should be given serious consideration.

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MEMORANDUM FOR FILE

INTRODUCTION

The capabilities and limitations of various forms of mobility systems for lunar exploration have been discussed and outlined in Reference 1. The objective of this memorandum is to develop a rationale and guidelines for the development of a Lunar Flying Unit (LFU). The specific end objectives are reliability, cost and development time. With these objectives in mind, a preliminary development plan is outlined to develop and qualify the flying system for lunar operations. It is recognized that several trade-off studies and parametric analyses in many areas will be required to select a final system configuration, however, the objective here is the recognition of the guidelines for performing such studies.

JUSTIFICATION

The justifications for the development of the LFU as an attractive tool for lunar exploration have been the subject of several detailed studies over the past several years (for example, see reference 2). It is not the intent of this memorandum to summarize the results of such studies, however, some of the pertinent features are briefly outlined below.

1. Irrespective of the type of proposed lunar exploration program, it is needless to emphasize the desirability of minimum trip time due to hostile lunar environment, limited stay time and limitations of the portable life support system. Of the various means of mobility systems investigated to date, the LFU certainly offers this potential.

2. One of the most attractive features of the LFU is its inherent rescue capability. Recognizing the various hazards of manned lunar exploration, a reliable rescue capability certainly does not require any further elaboration.

3. The LFU can significantly increase man's capability to investigate a number of scientifically interesting sites, such as a crater wall or central peak, which would be inaccessible either by surface mobility aids or by foot.

4. The LFU can provide mobility for ranges much greater than the presently conceived Local Scientific Survey Module (LSSM) or the walking capability of the astronaut.

5. The LFU can significantly contribute to enhanced safety of the astronaut due to minimum requirements for travel by foot, minimum trip times involved and rescue capability.

6. Based on current estimates, the dry weight of the LFU will be in the range of 150-185 lbs. Thus, the Augmented LM and even the Extended LM (Ref. 3) will have the capability to carry two LFU's as a part of the payload. Unlike the LSSM, the LFU does not depend upon the dual launch capability. For the dual launch missions, the LFU can be used for a variety of tasks which are complementary and not competitive with the roving type vehicles.

7. Based on the design criteria outlined in the text, the LFU can be developed and man-rated over a two year period for costs much less than currently estimated.

GROUNDRULES

Based on the specific objectives of reliability, cost and development time, it is proposed to develop a one-man LFU with the following characteristics. These groundrules are basically self-explanatory and thus require a minimum of elaboration.

1. The LFU should have a payload carrying capability of 370 lbs so that the vehicle may be used for rescuing a disabled astronaut. From an exploration standpoint, this payload capability is certainly quite attractive.

2. For simplicity and high reliability, the vehicle must utilize LM propellants.

3. From safety and efficiency standpoints, the vehicle should have a positive three-axis control.

4. The vehicle should have a one-way range capability of approximately 20 km. It is estimated that such a vehicle could visit 95% of all features of potential interest (Ref. 4) in the vicinity of a landing point.

5. The LFU should have a provision for some type of guidance so that the vehicle may be used for a variety of exploration profiles.

6. There should be a provision for two-way voice communication with the astronaut both in flight and after arriving at the exploration site.

7. The vehicle should be based on the concept of simplicity in design and operation and should utilize current state-of-the-art technology.

8. The overall design of the vehicle should be attractive from the standpoint of cost and development time.

9. The vehicle configuration should be oriented toward minimum spacecraft modifications.

10. The vehicle must be reusable with simple refueling and repressurization techniques.

11. The LFU engines should have a minimum operating lifetime of one hour.

VEHICLE CONFIGURATION

Conceptually, the vehicle may consist of a box type platform with various compartments which may be attached to the top deck of the main structure. Attachments may be provided for subsystem components and landing gear. The astronaut station and payload can be installed on the platform. [It is not intended in this memorandum to go into any detailed structural configuration. For a variety of configurations, for example, see Reference 5.]

It is proposed to utilize two horizontally mounted fuel and oxidizer tanks with positive expulsion (bladder type) which feed to three individual engines. The engines are similar in concept to the Surveyor vernier engines where two engines are fixed and one movable in a single plane. In order to provide three axis (pitch, roll and yaw) attitude control, differential throttling is to be utilized. Variable thrust can provide pitch and yaw control while roll control can be obtained by the movable engine. The engines can be clustered together or installed individually depending upon the merits of each configuration. (The cluster configuration may have the weight advantage and, possibly, may provide safe landing in case of failure of one engine while individual mounted engines may provide better vehicle maneuvering capability and better thermal characteristics.)

Based on the groundrules of minimum cost and development time plus high reliability, it seems prohibitive to enter into a new engine development program. The obvious answer is to utilize an engine which has been previously developed or is well downstream in the development stage which meets the performance requirements and design criteria for an LFU and requires minimum modifications. Also, the engine must have the inherent potential for a man-rated vehicle with minimum foreseeable problems.

Two potential engines which seem to reasonably fit the LFU flight criteria are described below.

A. Surveyor Vernier Engine

This engine, developed by Reaction Motors Division of Thiokol Corporation, utilizes N_2O_4 with 10% nitric acid as oxidizer and mono-methylhydrazine as the fuel. The fuel and oxidizer in each tank are contained in a bladder. The individual tank capacity is approximately 170 lbs. Helium stored under pressure is used to deflate the bladders. The tank pressure is approximately 700 psia. The engine is regeneratively cooled with a radiation cooled nozzle. The chamber pressure varies from 70 psia to 250 psia with a thrust variation of 30 lbs to 104 lbs. The specific impulse variation is from 260 seconds to approximately 285 seconds. Unofficial firing time on this engine is approximately 500 seconds. Also, most of the critical parameters and problem areas with this engine are known and well understood.

B. TRW MIRA-150A Engine

This engine, developed by TRW Systems, was a backup engine for the Surveyor vernier engine which was dropped in the final phase due to funding and compatibility problems. This engine, essentially, was a scaled down version of the LM engine which, for the Surveyor application, used a propellant combination of mixed oxides of nitrogen and monomethylhydrazine. The thrust chamber was ablative and had a duty cycle life of 300 seconds. The feed system, developed by Hughes Aircraft, operated at 700 psia. The engine had a thrust capability of 150 lbs maximum to 30 lbs minimum with a 5 to 1 throttling range. The chamber pressure varied from 22 psia to 110 psia with Isp variation of 250 to 291 seconds (nominal delivered). The nozzle was radiation cooled. The propellant flow control was accomplished by dual variable area cavitating Venturi valves. The program was concluded in late 1964.

In 1965, under a small NASA contract (NAS 8-20248) from MSFC, TRW explored the potential of applying the engine to a two-man lunar flying unit. The program required use of the LM propellants (N_2O_4/50% Hydrazine — 50% UDMH). The chamber life was supposed to be 3600 seconds. The program was quite successful within the framework of the fact that no changes were allowed to be made on the injector, chamber, etc. Operations at feed pressures of 250-300 psia were investigated. TRW demonstrated full life at 1.3 mixture ratio. These tank pressures are about the same as those used on the Gemini orbit maneuver control system.

Both of these engines have a desirable thrust range performance and design criteria to fulfill the requirements for the lunar flying unit. There is a considerable amount of experience available with these engines. The modifications required for adaptation to a LFU and to man-rate these engines with a longer lifetime will certainly be cheaper and less expensive than starting a new engine development program.

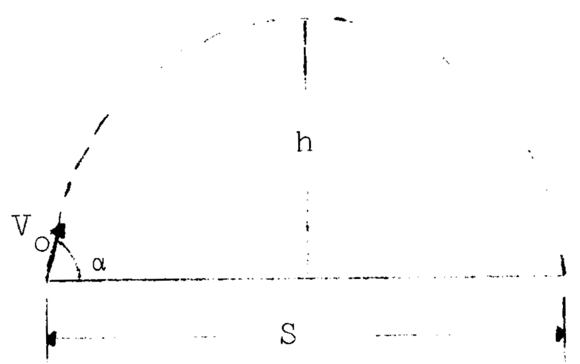
Of the two engines, the TRW MIRA-150A seems to have a lot of desirable features, such as low feed pressure, compatibility with LM propellants, and slightly better performance. Furthermore, a lot of hardware from the Gemini orbit maneuver control system may be effectively utilized for LFU application. However, there is a lot of experience available with the Surveyor vernier engine and most of the problem areas are well known. Thus, it is felt that a detailed study will be required to pick one engine over the other for LFU application.

In order to get some cost estimates and development time required for modifications, adaptation and to man-rate these engines for the LFU application, the current status of these engines were evaluated. Based on past experience and current contractor capabilities, cost estimates in the range of 3 to 5 million dollars seems realistic. The expected modification and qualification program can be conservatively carried out over a period of 18 to 24 months. If, however, a new engine development program is proposed, cost estimates in the range of 18 to 25 million dollars and development time of approximately 36 months can be reasonably expected.

MODE OF APPLICATION

There has been some concern and discussion as to the mode of application for the LFU. While it is apparent that the ballistic trajectory would be most economical from the point of view of fuel consumption, however, it has several undesirable features such as high velocities, high accelerations and high altitude, which are unattractive from an exploration and safety standpoint and, furthermore, may require sophisticated guidance, communication and control systems. On the other hand, a horizontal flight has the desirable features of relatively low velocities, low accelerations and low altitude but is uneconomical from the standpoint of fuel consumption. While this study requires a detailed computer analysis, a simple approximate calculation is shown below as an example.

Ballistic Flight



$$V_v = V_o \sin\alpha - gt \text{ (vertical)}$$

$$V_h = V_o \cos\alpha \text{ (horizontal)}$$

$$S_v = V_o(\sin\alpha)t - 1/2\, gt^2$$

$$S_h = V_o(\cos\alpha)t$$

Initially and finally $S_v = 0$ or

$$V_o(\sin\alpha)t - 1/2\, gt^2 = 0 \text{ or } t = \frac{2\, V_o \sin\alpha}{g}$$

Thus, distance $S = V_o \cos\alpha \dfrac{2\, V_o \sin\alpha}{g}$

$$= \frac{V_o^2 \sin 2\alpha}{g} \text{ or}$$

$$V_o = \sqrt{\frac{Sg}{\sin 2\alpha}} \quad \text{and } h = \frac{V_o^2}{4g} \quad \text{for } \alpha = 45°,$$

$$\text{Total } \Delta V = 2\sqrt{\frac{Sg}{\sin 2\alpha}}$$

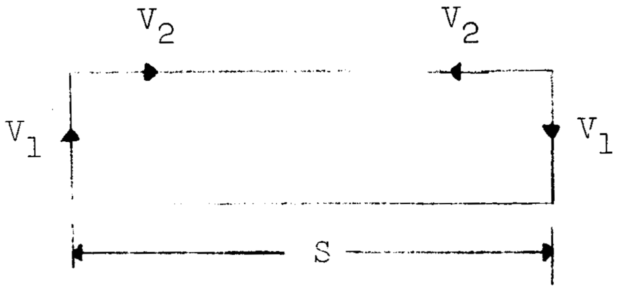
For no stops and assuming a range of 60,000 ft and $\alpha = 45°$,

$$\Delta V = 1{,}140 \text{ ft/sec and h (altitude)} = 15{,}000 \text{ ft}$$

With one stop

$$\Delta V = 1{,}616 \text{ ft/sec and h (altitude)} = 7{,}550 \text{ ft}$$

Horizontal Flight



$$\text{Total } \Delta V = 2\ V_1 + 2\ V_2 + gt$$

$$S = Vt \text{ or } t = \frac{S}{V}$$

Assuming an astronaut can travel at 200 ft/sec, for a distance of 60,000 ft with no stops

$$gt = 5.4 \times \frac{60{,}000}{200} = 1{,}620 \text{ ft/sec}$$

$$2\ V_2 = 400 \text{ ft/sec (velocity to get from 0 to 200 ft/sec)}$$

Assuming the astronaut wants to fly at 100 ft altitude and assuming a thrust to weight ratio of 2,

$$h \text{ (altitude)} = g\left[\left|\frac{T}{W}\right| \sin\alpha - 1\right]\frac{t_b^2}{2} \text{ or } t_b = 6.1 \text{ sec}$$

Thus

$$2\ V_1 = 2\ gt_b = 66 \text{ ft/sec } (t_b = \text{burntime})$$

Thus

$$\text{Total } \Delta V \text{ with no stops} = 1620 + 400 + 66 = 2086 \text{ ft/sec}$$

$$\text{Total } \Delta V \text{ with one stop} = 2552 \text{ ft/sec}$$

This example gives some idea of ΔV penalty for the non-optimum use of the vehicle.

COMMUNICATION

The communication system requirements may be provided in the form of a data channel. Some of the mission function requirements are described as follows:

*1. Two way voice communication with the astronaut, both in-flight and after arriving at the exploration site

*2. Astronaut biological telemetry data

3. Vehicle systems status

4. Telemetry of vehicle flight parameters for determination of vehicle performance

5. In-flight and on site scientific measurements

Due to line of sight constraints and equipment compatibility considerations, a return to earth routing may be quite attractive. This can use S-band equipment similar to that on the LM. The main advantage of this is the direct contact with MSFN stations.

The other possibilities may be multiple lunar surface VHF repeater stations or routing via the CSM. However, the first one seems to have the installation problem and the second one has the drawback of not providing continuous coverage.

Electrical Power

One of the means of providing an electrical power source on the LFU is by the use of silver zinc battery cells. Bell Aerosystems made a rough estimate of power requirements based on the worst case sortie which consisted of several flights. Their estimate was 14 ampere-hours. This included a 100% reserve safety factor including 15% reserve for six months wet charged storage loss; 20% reserve for loss of efficiency following multiple cycles of discharging and charging; 25% reserve for temperature effects; and the remaining 40% for general safety factor reasons.

Guidance and Control

The guidance system for the LFU should be simple, easy to use and efficient at all ranges.

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*Requirements 1 and 2 are the same as provided by a PLSS unit, however, the range will have to be extended. The present range for PLSS is approximately one mile to the LM.

Since the flight paths, essentially, will be in one plane and due to the relatively short ranges involved, it may be desirable to utilize a strap down gyro system employing rate integration. By straightforward integration of the acceleration outputs, altitude and along course rate and position information may be obtained. A radar altimeter can be used for altitude information. For backup purposes a simple timer may be employed.

It is conservatively estimated that, including the cost of development of all subsystems and system integration, the LFU configuration program can be carried out for an approximate cost of 10 million dollars over a two year period. This figure does not include the cost of test facilities and simulation of lunar environment for overall configuration checkout.

CONCLUSION

A rationale and guidelines for the development of a Lunar Flying Unit for lunar exploration are briefly outlined and discussed. The program seems justifiable and feasible. The LFU can be developed and man-rated over a two year period for an overall approximate cost of 10 million dollars. It is recommended that this should be given serious consideration.

R. Sehgal

R. Sehgal

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Attachment:
References

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From: R. Sehgal

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